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AN ABNORMAL WAVE IN LAKE ERIE.[1]

HOWARD S. REED.

ON July 19, 1895, between 8 and 9 P.M., in the vicinity of Erie, Pa., the waters of Lake Erie suddenly rose in a single wave about six feet high, which advanced upon the shore and after a few moments quietly subsided to their former level. Five miles west of Erie the rise was but three or four feet, and three distinct rises were observed; the first and second rises were about fifteen minutes apart, the second and third about half an hour apart. Fifteen miles east of Erie the rise was about six feet, and but one wave was observed.

The weather on the day referred to was calm and clear where the rise occurred, and had been pleasant on each of the two preceding days, with light variable winds most of the time, and a range of temperature from 80° to 90° *F.*

On the evening of the 19th the sky was cloudy, as if a storm were approaching. All day long the lake had been very calm.

Mr. R. J. Moorehead thus describes the phenomenon, as observed off North East, Pa.:

"Between eight and nine o'clock, while we were sitting near the shore of the lake, the water suddenly rose about six feet, vertically, running back on the beach about sixty feet. But for the sharply shelving beach just at the water's edge, many would undoubtedly have been drowned.

"The day had been calm, no wind, thermometer 91° *F.* in the afternoon.

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"When the water subsided, it receded to a distance of fifty-six feet out beyond its normal margin. I paced it during the comparative repose following the recession of the flood, though in a very few minutes it began to assume its normal condition. The flood and outflow did not occupy over a very few minutes, I should say not over five minutes.

"This was followed by calm (no wind during this time) for about ten minutes, when we heard a low ominous roar, gradually increasing in volume, which we knew was the wind coming down the lake; the first visible evidence of it was of wave after wave chasing each other with cumulative force, *directly down the lake*, nearly at right angles with the shore. Every wave was crested, and coming so swiftly (they went like a pack of hounds) that when they struck the rock-bound shore, one hundred yards below us, they took a tangent to the northeast; thus driving their foaming mass out, into, and diagonally across the waves whose course, not having been diverted, was due east, and caused this agitated mass of water to rear and plunge, traveling swiftly like a thing of life, out as far as we could see, as it was now becoming dusk, though still light."

A young man who was bathing in the lake at that point says that the water which came in was very cold and seemed very heavy compared with that which it displaced.

This strange behavior of the lake excited no little comment at the time, and many were the conjectures made to explain the phenomenon. The older people related a similar occurrence which took place some fifty years ago and drowned sheep in lowland pastures.

The 19th of July opened with threatening weather at all stations at the western end of the lake. Between 2.15 and 4 A.M. rain fell at Detroit and at Toledo. At 8 A.M. the observers at Detroit and Erie reported a south wind; the other stations reported a southeast wind. The average velocity of the wind was about seven miles an hour. The barometer was highest at Buffalo, gradually becoming lower toward the western end of the lake. At most of the stations the thermometer was above 90° *F.* at some time during the day, and the muggy atmosphere made the heat the more depressing.

The first indication of any unusual disturbance was at 1.10 P.M., when a small tornado struck the town of St. Clair, Mich. Trees were blown down by the hundreds, and about a dozen houses were seriously damaged. The wind was accompanied by a driving, soaking rain which lasted about thirty minutes. But the tornado was seemingly local in character, as the wind at Marine City, Lenox, and Memphis (near-by towns) was but a zephyr. It is doubtful whether this local stationary storm had any influence directly upon the meteorology of the surrounding country, although it may have started upper air currents, which might have produced results later, especially if it caused high westerly currents.

According to Davis, thunderstorms are often caused in this way, when the higher members of westerly currents overrun the southerly winds for a considerable distance eastward of the line which separates the two winds at the surface of the earth.

At 4.15 P.M., at Detroit, the first thunder of an approaching thunderstorm was heard, and at about 4.30 heavy rain began to fall, ending at 6.40 P.M.

At Toledo the wind had been generally southwest until 4.30 P.M., when a squall suddenly increased it to a gale from the northwest. The flagstaff halyards at the observing station were blown loose and caught around the cups of the anemometer, holding them fast and causing a loss of record until 7.50 P.M. It is estimated that the wind attained a velocity of forty-two miles per hour, with an extreme of sixty, during the first ten minutes of the squall. The barometer fell slowly until 4.20 P.M., then rose suddenly 0.07 inches and remained nearly stationary the rest of the day. The temperature rose rapidly during the day; just before the squall it registered 93°, but fell to 71° *F.* from 4.30 to 5 P.M.

At Point Pelee Island the wind had been blowing from the east and southeast since noon of the 18th. At about 5 P.M. on the 19th a squall increased its velocity from sixteen to twenty-four miles per hour, and changed, oppositely, its direction from east to west, whence it gradually changed to northwest, to northeast, and back to east. Accompanying the squall was the thunderstorm.

Sandusky, Ohio, experienced the gale and rainstorm without thunder. The wind there attained a velocity of fifty miles an hour.

The observer at Cleveland reported brisk variable winds veering from northwest to east, with storm velocities from 6.55 to 7.25 P.M.

The thermometer had risen to 79.2° *F.* at Port Stanley, Ontario. The direction of the wind from 1 A.M. to noon of the 19th had been east and southeast; from noon to midnight the direction was northeast. During the earlier part of the day the velocity of the wind had ranged from ten to seventeen miles per hour, but in the afternoon the velocity gradually diminished, until at 7 P.M. it was but four miles an hour. After the passage of the thunderstorm, which must have occurred here shortly after 7 P.M., the wind velocity suddenly increased to fifteen miles an hour, dropping back, however, to three miles an hour by 9 P.M. and continuing gentle the rest of the night. The thunderstorm reached Port Dover at 7.30 P.M., and there also caused fresh north and west winds.

The meteorological observer at Erie gives the following report for the day: "Very warm and depressing all day, squally at night. A tidal wave six feet high moved from the northwest at 9 P.M. The wind jumped from seven to twenty-four per hour, was severe, but no damage reported."

The observer at Buffalo says: "Generally fair in daytime, with some threatening conditions in morning, and in the evening rain fell shortly after the 8 o'clock observation, continuing showery during the balance of the evening; warm and sultry, with light variable winds. Distant thunder in the southeast."

At Welland, Ontario, the day was partly clear; the highest temperature was 91° *F.* The thunderstorm occurred there at 8 P.M. Niagara experienced much the same kind of weather as Welland, except that the temperature was somewhat lower and the precipitation not nearly so great.

Ordinary lake waves, as is well known, are due to the action of the wind. The friction of the wind on the surface of the water causes undulations in the water which travel in the same direction as the wind. After the wind which caused the waves has subsided, the gradually diminishing undulations may continue for some time. These undulations are known as the "swell."

From time to time observers near lakes have noticed movements in their waters which could not be classed as ordinary waves. Any such unusual rise of water is popularly termed a "tidal wave," but in reality the tides in lakes are too slight to be detected by any but the most delicate observations. It is much more probable that such disturbances are caused in one of the following ways:

When a heavy wind blows nearly parallel to the length of a rather narrow lake for a day or so, the waters move with it and rise on the shore against which they are driven. In November, 1892, a storm from the west caused the waters of Lake Erie, near Toledo, to fall eight or nine feet below the normal fair-weather level. At the same time unusually high water was experienced at the eastern end of the lake.

Sudden changes in the outlet of a lake may produce changes in the level of its water; as when an outlet is dammed by an ice gorge or by an avalanche.

Earthquakes produce waves in bodies of water, but there are no instances recorded of such waves in lakes.

A *seiche* is a change of level in the waters of a lake, supposed to be due to changes of barometric pressure on different portions of the water surface. There are also certain rhythmical pulsations, producing a difference of level of three or four inches during calms, when no similar variation of atmospheric pressure can be detected.

The seiche has been quite thoroughly studied in the lakes of Switzerland, particularly by Forel, but although similar movements are known to occur in our great lakes, the subject here is one which awaits investigation.

The rise of the waters of Lake Erie, under consideration, was evidently one of these exceptional movements of large water bodies, and by noting the conditions under which it took place we may be able to gain some knowledge as to their causes.

Was it an earthquake wave?

We can be almost certain that it was not; for if any earthquake shock had occurred at that hour of the day, it would have been noticed at some point on the shore, or by some vessel on the lake, which was not the case. Furthermore, an earthquake wave of the size noted would not be local, but probably would be noticed at many, if not all, points on the lake shore.

Was it an example of water piled by the wind?

We can be quite sure that this was not the cause, for on the previous evening there was a calm area near the locality where the rise occurred, away from which the wind blew in three or four different directions. And although, after sunrise on the 19th, the wind kept a generally southeast direction, with an average velocity of nine miles an hour, we may be quite sure that so light a wind, blowing upon a large body of water for so short a time, at right angles to its longer axis, could not have been the cause of the phenomenon.

It may be asked if a difference of barometric pressure might not account for the difference of level of the water.

It is very possible that this may be an indirect cause of the rise, but it is not competent in itself to produce such a change in level. By reference to the barometric conditions for the 19th, it will be seen that there was a "high" area near the central portion of the lake at 8 P.M., where the barometer was 0.08 to 0.09 inches higher than at either end of the lake. As a column of mercury thirty inches high corresponds to a column of water thirty-four feet high, the column of water able to be supported by the pressure in the "high" area would only differ about an inch from the column able to be supported by the pressure at either end of the lake. So the water in the central portion of the lake would only need to fluctuate about half an inch in order to establish its equilibrium.

Was the phenomenon a seiche?

Forel gives as causes of seiches: (*a*) rapid local variation of atmospheric pressure; (*b*) relaxation of the wind which has heaped the lake waters up to one side; (*c*) a gust of wind striking the lake obliquely; (*d*) electrical attraction; (*e*) avalanche winds; (*f*) earthquakes; (*g*) storms.

Some of these causes were incontestably present at the time this phenomenon occurred.

We had a heavy gust of wind striking the lake obliquely as a characteristic result of the thunderstorm. All stations at the western end of the lake reported a gale from the northwest as accompanying the thunderstorm.

Another of the causes which was present was a storm. Whether the storm was the principal cause or not, is difficult to say ; although, by agitating parts of the lake and causing an unstable equilibrium in the atmosphere, it undoubtedly entered in as a cause.

Theoretically, at least, electrical attraction would have some influence upon the action of the water; but owing to our present incomplete knowledge of the subject we do not know how great the actual effect would be.

In the opinion of the writer the oblique blow given to the water by the northwest wind, and the agitation of water and atmosphere, caused by the storm, were the principal factors causing the result.

This theory seems to be supported by the account of the eyewitness who described the northwest wind following the wave.

There are objections, though, to calling it a seiche. A true seiche is a rhythmic oscillation of the surface of a lake, whereas in this case oscillations seem to have been lacking at some places.

One of the most puzzling circumstances in connection with this phenomenon is the fact that where the wave seems to have struck the shore first, *i.e.*, about five miles west of Erie, where the water is shallow for about four miles out, there were three waves; while fifteen miles east of Erie, where the water is deeper, there was but one wave. In investigating the cause for this change in the make-up of the wave we should encounter much theory and speculation, which would not be entirely reliable unless we knew all the attending conditions. But we can say one thing with some degree of certainty, *viz.* : if the direction of the waves made an angle of less than 45° with the shore line, the first wave striking the shore would be reflected at such an angle that it will meet and combine with the second wave and form a resultant wave farther along the shore. This wave, in turn, would be reflected from the shore and reënforce the third wave.

The study of seiches in this country is just beginning to receive attention, and there are some questions about them that we will have to leave unanswered until more definite knowledge is obtained concerning them.

After we have pointed out as many causes as we are able we will probably find ourselves repeating the words of G. H. Darwin, when he writes: "Although it is possible to indicate causes competent to produce seiches, we cannot as yet point out the particular cause for any individual seiche. The complication of causes is so great that this degree of uncertainty will probably never be entirely removed."

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